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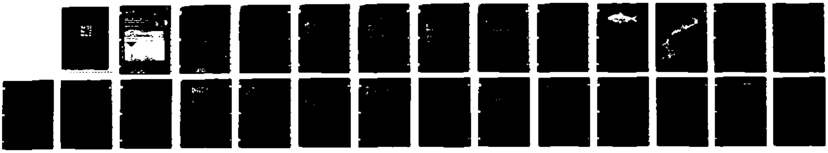

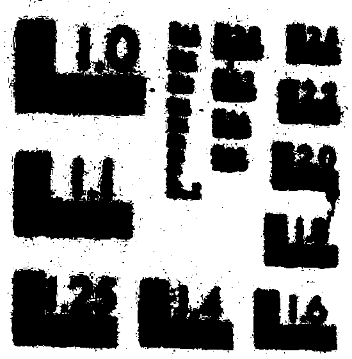

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Biological Report 82(11.59)
July 1986

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic)

AMERICAN SHAD

Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic)

AMERICAN SHAD

by

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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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Post Office Box 631
Vicksburg, MS 39180

Keywords: → cont'd pg 1

CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees	0.5556(°F - 32)	Celsius degrees

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TABLES

ACKNOWLEDGMENTS

We thank Henry J. Booke, Massachusetts Cooperative Fishery Research Unit, University of Massachusetts; Richard Neves, Virginia Cooperative Fish and Wildlife Research Unit, Virginia Polytechnic Institute and State University; Christine Moffitt, Idaho Cooperative Fishery Research Unit, University of Idaho; and Stephen Rideout, U.S. Fish and Wildlife Service, for reviewing the manuscript.

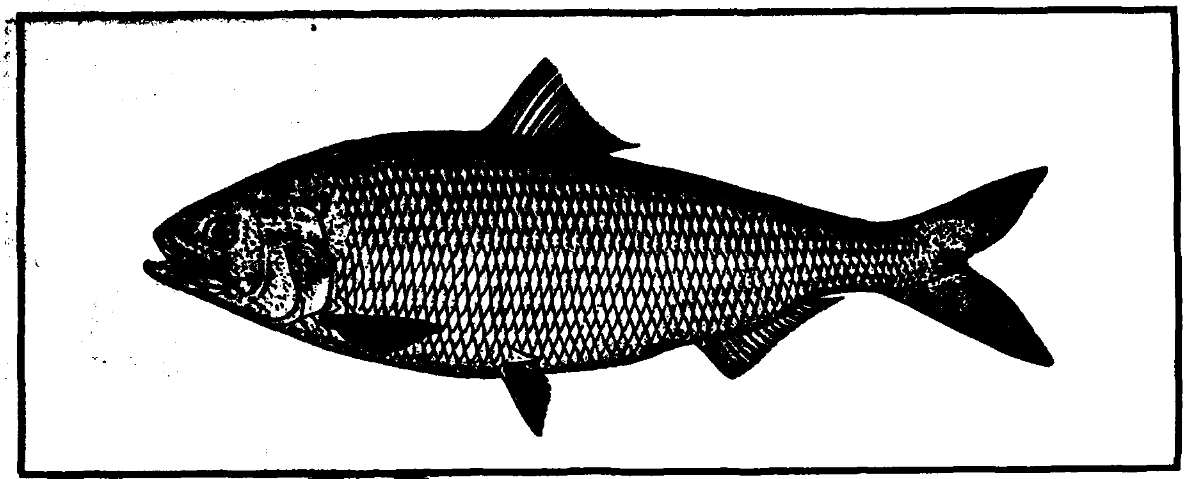

Figure 1. American shad; Alosa sapidissima;

contd

AMERICAN SHAD life cycles; habitat; spawning; marine biology

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . *Alosa sapidissima* (Wilson)
Preferred common name . . . .American shad (Figure 1).
Other common names . . Shad; alose; common shad; Atlantic shad; North River shad; Delaware shad; Susquehanna shad; white shad; buck shad (males only), poplarback shad (Scott and Crossman 1973).
Class . . . . Osteichthyes
Order . . . . Clupeiformes
Family . . . . .Clupeidae

Geographic range: American shad are anadromous. They are distributed along the Atlantic coast from Newfoundland southward to Florida, and are most abundant from Connecticut to North Carolina (Figure 2). On the Pacific Coast, the American shad was introduced into the Sacramento and Columbia Rivers in 1871, and is now established from southern California northward to Cook Inlet, Alaska, and westward to the Kamchatka Peninsula in Asia.

MORPHOLOGY/IDENTIFICATION AIDS

Body elongate, deep (its depth is 17%-19% of its total length [TL]) strongly compressed laterally (Leim 1924; Bigelow and Schroeder 1953; Scott and Crossman 1973). Head broadly triangular, 22%-24% of TL. Gill membranes free from isthmus. Eye moderate, adipose eyelid well developed, diameter of eye 27%-32% of head length (HL); snout moderate, length 27%-32% HL; interorbital width 19%-22% of HL. The anterior end of the lower jaw not excessively thick or heavy, somewhat pointed, and fitting easily into a deep notch in upper jaw; jaws are about equal when the mouth is closed. The upper outline of the lower jaw slightly concave. Maxillary extending to posterior margin of eye. Teeth small, weak, and few in number on premaxillary and mandible (lost completely in the adult) and absent on the roof of the mouth. Gill rakers on lower limb 59-73; branchiostegal rays 7,7 (rarely 7,6). Fins soft rayed: dorsal-1, height moderate, base short, 11%-13% of TL, rays 15-19, usually 17-18; caudal, distinctly forked;

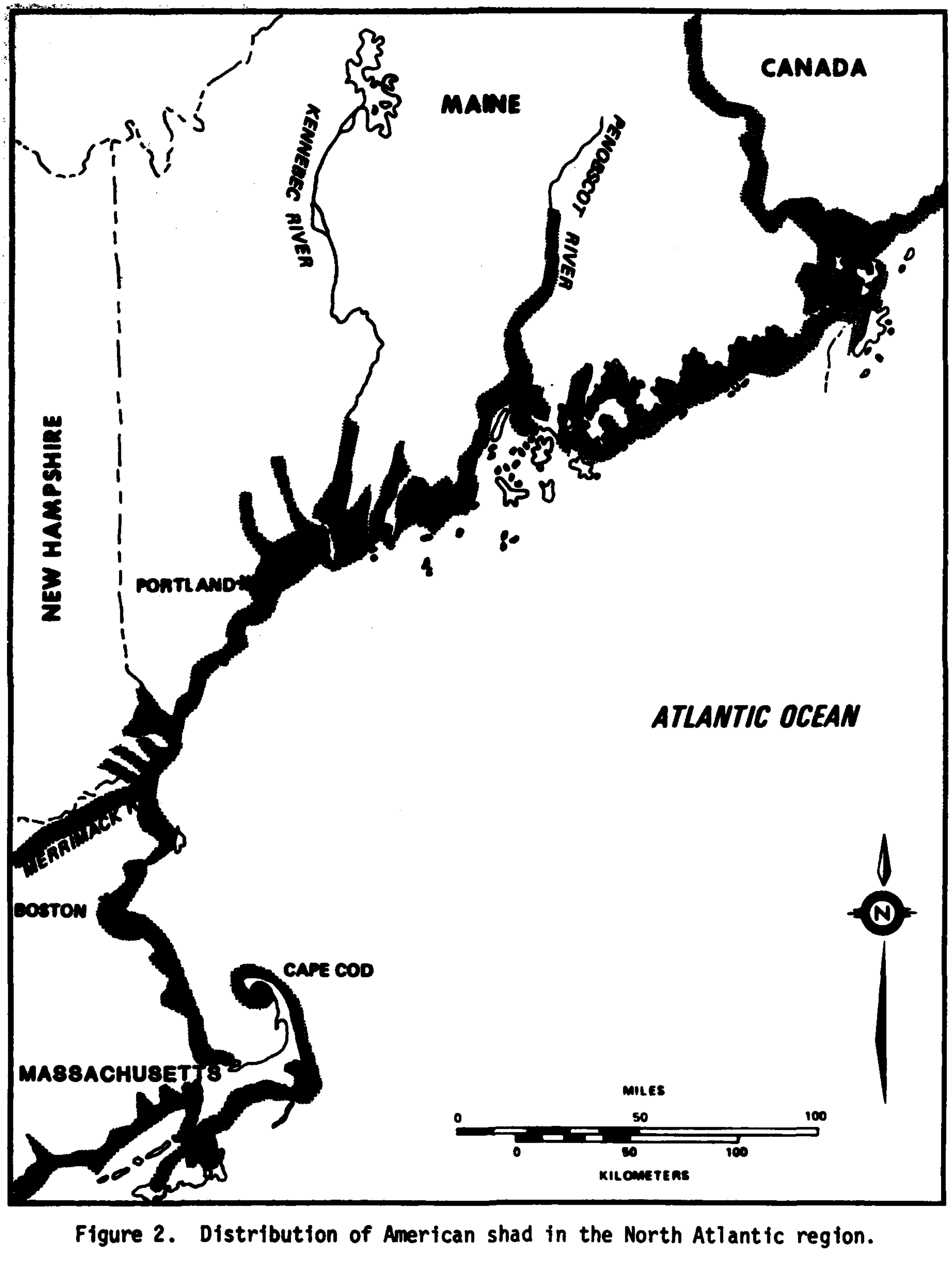

Figure 2. Distribution of American shad in the North Atlantic region.

anal-1, base length greater than dorsal base, 13%-14% of TL, height shorter than dorsal height; rays 18-24, usually 20-22; pelvics, abdominal, small, length 9%-10% of TL, rays 9; pectorals, low on sides, length 14%-15% of TL, rays 14-18, usually 16. Scales large, crenulate on posterior margin, deciduous. Lateral line poorly developed with about 50-55 scales. Ventral scutes well developed forming a sharp sawbelly, prepelvic scutes 19-23, usually 20-22; postpelvic scutes 12-19, usually 15-17. Vertebrae 53-59, usually 55-58. Peritoneal lining pale; pyloric caeca numerous and usually clustered on right side. Usually 4 to 6 black spots in horizontal row behind operculum. Size: average length in fishery 380 mm; males 0.7 to 2.7 kg (1.5 to 6.0 lb); females 1.6 to 3.6 kg (3.5 to 8.0 lb), rarely to 5.4 kg (12 lb).

REASON FOR INCLUSION IN SERIES

Historically, the commercial fishery for American shad along the Atlantic coast was widespread and intense. The fishery now is generally reduced and important only in some waters. In rivers in the North Atlantic that still support spawning runs, the sport fishery is more important than the commercial fishery. Federal and State agencies have programs aimed at restoring American shad to their former range and abundance. If these programs are successful, then protection or mitigation of the shad must be considered in future coastal and riverine development projects.

LIFE HISTORY

Spawning

The American shad is an anadromous fish that lives several years in the ocean and then returns to its natal river to spawn. The species probably has spawned in virtually every accessible river and tributary along the Atlantic coast.

Shad spawn as early as mid-November in Florida and as late as July in some Canadian rivers. The males arrive at the spawning grounds before the females. The time of spawning migration is regulated by water temperatures in the river. Spawning begins when the water temperature reaches 12 °C (54 °F) and continues as long as the temperature does not drop much below 12 °C (54 °F) or exceed 20 °C (68 °C). An increase in temperature is the primary "trigger" for spawning, but photoperiod, flow velocity, and water turbidity also are factors (Leggett and Whitney 1972). The spawning run peaks at a temperature of about 18 °C (65 °F) and the range is 13 to 20 °C, or 56 to 68 °F (Walburg and Nichols 1967).

Spawning sites are the same from year to year. Shad spawn at night, usually in shallow water with moderate currents in the main stem of rivers (Marcy 1972). Spawning behavior has been described by Medcof (1957) and Layzer (1976). A chase is probably involved; males following females in a tightening circle. Spawners sometimes splash at the surface. Eggs are released between sundown and midnight in the open water where they are fertilized by the males (Scott and Crossman 1973).

Most shad in the Connecticut River make their first spawning run when they are 4 or 5 years old (Table 1). Almost all shad 6 years old have spawned at least once.

The percentage of shad that have spawned and return to spawn again (repeat spawners) increases from south to north. Shad native to rivers south of Cape Fear, North Carolina, apparently die after spawning. In rivers north of latitude 35 °N, some shad survive, return to the ocean, and

Table 1. The percentage of first-time spawners in the Connecticut River spawning run (Leggett 1976).

Age	Mean	Standard deviation
III	7	2
IV	23	6
V	29	8
VI	3	2
VII	0	

Table 2. The percentage of repeat spawners in American shad populations in Atlantic coast rivers (Leggett and Carscadden 1978).

River	Latitude of river (°N)	Repeat spawners(%)
Miramichi	49	64
St. John	45	73
Connecticut	41	63
Hudson	41	57
Susquehanna	40	37
Potomac	38	20
York	37	24
James	37	27
Neuse	35	3
Edisto	33	0
Ogeechee	32	0
St. Johns	30	0

spawn again the next year. Shad in the north have a higher percentage of repeat spawners than in the south (Table 2).

Fecundity and Eggs

The American shad has a relatively high fecundity (Table 3), generally decreasing from south to north (Table 4). Unfertilized eggs are 2 mm in diameter; fertilized, water-hardened eggs are 3 mm in diameter, semibuoyant, non-adhesive, and transparent, pale pink or amber (Marcy 1976). The eggs are carried along by the current and hatch in about 8 to 12 days at 11 to 15 °C, or 52 to 59 °F (Scott and Crossman 1973). Shad eggs hatched in only 3 days at temperatures of 14 to 23 °C (57 - 73 °F) in the laboratory (Marcy 1976).

Larvae to Adults

Newly hatched larvae are about 7 mm long and are planktonic (Marcy 1976). They are 12 mm long when the yolk sac is absorbed, and 25 to 28 mm long and 2 to 3 weeks old upon metamorphosis to the juvenile stage (Jones et al. 1978). The juveniles spend the first summer in the river. The morphological characteristics of larvae during development have been described by Jones et al. (1978).

Table 3. Lengths, weights, and ages, and the range of the number of eggs (in thousands) among individual American shad populations of seven Atlantic coastal rivers of the United States, 1951-59 (Walburg and Nichols 1967).

River	Fork length (mm)	Body weight (kg)	Age (years)	Range of number of eggs (x 1,000)
Hudson	355-556	0.8-3.0	III-IX	116-468
Potomac	460-505	1.4-2.4	V-VI	267-525
York	399-470	1.1-2.1	IV-VI	169-436
Neuse	447-498	1.8-2.7	IV-VI	423-547
Edisto	465-498	1.6-2.2	IV-VI	360-480
Ogeechee	457-475	1.7-2.2	IV-VI	359-501
St. Johns (FL)	368-460	0.6-1.8	IV-VI	277-659

Table 4. Mean virgin and lifetime fecundities of American shad populations in five Atlantic coast rivers (Leggett and Carscadden 1978).

River	Virgin fecundity	Lifetime fecundity
St. Johns (FL)	406,000	406,000
York (VA)	259,000	327,000
Connecticut (CT)	256,000	384,000
St. John (NB)	135,000	273,000
Miramichi (NB)	129,000	258,000

In the fall, juveniles (75 to 125 mm long) move to brackish water, then to the sea. Decreasing water temperature in the rivers is the primary stimulus for downstream movement. Juveniles migrate seaward first in northern rivers and progressively later in rivers to the south (Leggett 1977a). Juvenile shad start downstream in the St. Johns River, Florida, as the water cools to 15.5 °C or 60 °F (Walburg 1960). In the Delaware River, shad begin moving downstream at a water temperature of 20.5 °C (69 °F); movements peak at 15.5 °C or 60 °F (Sykes and Lehman 1957). Peak downstream migration is in late September and October in the Connecticut River, in late October in rivers tributary to Upper Delaware Bay, and in late November in rivers tributary to the Chesapeake Bay (Leggett 1977a).

Shad remain in the ocean until mature. Males mature when 3 to 5 years old; females mature when 4 to 6 years old (Leim 1924). The oldest shad examined in the Bay of Fundy was 9 years old. The oldest shad in the United States was 11 years old and 584 mm long (Scott and Crossman 1973). The only self-sustaining, landlocked population of American shad is in the Millerton Reservoir-San Juan River system of California (Lambert et al. 1980).

Migration

American shad along the Atlantic coast form common schools and undertake extensive ocean migrations (Leggett and Whitney 1972). These migrations are partly regulated by changes in bottom water temperatures. American shad seem to prefer bottom temperatures between 3 and 15 °C (37 and 59 °F) and are most concentrated at temperatures between 7 and 13 °C or 45 and 55 °F (Neves and Depres 1979).

Along the mid-Atlantic coast, shad move offshore to deeper water in winter (Talbot and Sykes 1958). In March and April, the schools move toward the coast. Shad returning to rivers south of Cape Hatteras follow the Gulf Stream, remaining in the 3 to 15 °C (37 - 59 °F) bottom isotherm. Shad migrating to north Atlantic rivers do so later in spring, following a route farther to sea because of preferred offshore temperatures in the Middle Atlantic Bight. On the basis of tag returns, some fish, however, migrate north along the coast (Neves and Depres 1979).

In summer and fall, shad congregate in the Gulf of Maine and the Bay of Fundy. This congregation includes immature shad from Atlantic coast rivers and spawned-out adults from streams north of Chesapeake Bay. American shad migrate at the rate of 21 km/day (13 mi/day) between Chesapeake Bay and the Bay of Fundy (Leggett 1977a). They migrate up to 3,000 km (2,000 mi) in one season.

The American shad homes to its natal river to spawn. Dodson and Leggett (1974) believe homing is based on olfaction (smell) and rheotaxis (orientation to current) in the Connecticut River and probably elsewhere. The direction and goal of migration appears to be determined by olfaction of chemicals, and the orientation along the migratory path is determined

by tidal and river currents. The orientation mechanism is sufficiently robust that migrations continue even after major changes in water flow, such as after the construction of headponds of hydroelectric facilities. Homing is fairly precise but a few individuals ascend rivers other than in their natal stream to spawn.

The timing of entry of shad into rivers is highly dependent on water temperatures. The peak migration into freshwater thus is earlier in the south than in the north. Runs peak in January in Florida and in June and July in New Brunswick and Quebec (Walburg and Nichols 1967; Leggett and Whitney 1972). Shad migrate in the Connecticut River at temperatures between 16.5 and 21.5 °C (62 and 71 °F). American shad tend to discontinue upstream movement at temperatures greater than 20 °C (68 °F) (Kuzmeskus 1977).

Shad spawn far enough upstream for eggs to drift and hatch before reaching saltwater. Low water temperatures in the spring may delay gonadal maturation, resulting in a longer period of upstream migration prior to spawning (Marcy 1976). These migrations may extend as far as 800 km (500 mi) inland. The maximum distance in most rivers is now limited by natural and human-made obstructions.

AGE AND GROWTH

Age and growth can be evaluated by examining scale structures. Judy (1961) verified the scale method of aging American shad, and also observed a mark on the scale that formed when the juvenile left fresh water. Shad grow about 100 mm per year until sexually mature, when growth slows (Table 5). American shad live 5 to 7 years and may reach a weight of 1 to 3 kg.

The relations between total weight (W) in grams and fork length (FL) in mm for fish captured prior to spawning at Lambertville on the Delaware River are W = 8.09 FL - 2335 for males and W = 11.54 FL - 3764 for females (Chittenden 1976). Valid ranges for linear interpolation were 330 to 520 mm for males and 410 to 550 mm for females. Length-weight relationships after spawning were W = 3.245 FL - 783 for males and W = 3.01 FL - 697 for females. Valid ranges for linear interpolation were 265 to 450 mm for males and 340 to 475 mm for females. The average total weight loss during the spawning run in the Connecticut River was 45%-60% (Glebe and Leggett 1981). Tissue loss was greatest in small fish and in fish exposed to higher temperatures.

Wilk et al. (1978) calculated the relation of weight in grams to total length in millimeters to be log W = -5.3994 + 3.2255 log TL, for 294 shad collected in the New York Bight. No significant difference between the sexes was observed.

COMMERCIAL/SPORT FISHERY

History of the Fisheries

During the 19th century, extensive fisheries for shad developed along the entire Atlantic coast. Shad

Table 5. Ages and corresponding average total lengths of shad in the Bay of Fundy (Leim 1924).

Growing season	Age group	Length (mm)
1st	0	120
2nd	I	240
3rd	II	320
4th	III	400
5th	IV	470
6th	V	520
7th	VI	570

were captured in rivers and in coastal waters. Major gear developed and preferred in different locations were drift and staked gill nets, pound nets, haul seines, weirs, fyke nets, bow nets, and dip nets. The estimated Atlantic coast catch in 1896 was 50 million pounds (23,000 t), but between 1930 and 1960, the annual catch was about 10 million pounds (Table 6). Since 1960, the catch has declined further, principally due to dams, pollution, and overfishing. The Atlantic coast catches are greatest in Chesapeake Bay (Table 7).

Table 6. Annual shad landings (thousands of pounds) and value (thousands of dollars) for the U.S. Atlantic coast (Walburg and Nichols 1967).

Year	Weight	Value
1880	18,068	995
1887	29,630	---
1888	33,397	1,665
1896	50,499	1,651
1908	25,935	2,092
1929	13,955	---
1930	10,373	---
1931	11,336	---
1932	9,272	---
1935	8,236	860
1937	9,647	---
1938	9,720	---
1939	10,075	---
1940	9,964	905
1945	14,699	2,500
1950	8,223	1,596
1951	8,477	---
1952	10,521	---
1953	7,799	---
1954	8,668	---
1955	8,599	1,422
1656	9,672	---
1957	11,369	---
1958	8,186	---
1959	8,200	1,086
1960	8,134	1,107

Present Fishery

In New England, the principal American shad fishery is on the Connecticut River, where a small commercial fishery and sport fishery exist. About 3,000 lb (1.4 t), were landed in Massachusetts in 1979. Merriman (1970) gave capitalized annual value to the Connecticut River of $75 million for the commercial fishery and $14 million for the sport fishery.

In Maine, about 95% of the river habitat once used for spawning is now blocked by impassable dams (Flagg et al. 1979). Shad runs in Maine are estimated at no more than several thousand fish annually and no more than 100 to 600 adult shad are caught in a small sport fishery. A fishery specific for American shad is non-existent; catches are incidental to those of other species. If restoration is completed as planned, a possible annual harvest of 1.5 million pounds (680 t) is projected. If adequate fish passage facilities are constructed, 6,000 to 10,000 mi^2 (15,000 to 25,000 km^2) of additional river would be available to shad.

New Hampshire currently has no commercial regulations for shad; however, there is a two fish per day bag limit for hook and line fishermen.

Massachusetts has banned commercial fishing for shad. The sport fishery in marine waters for American shad is restricted, but in freshwater the limit is six fish per day.

The commercial fishery in the Connecticut River employs drifting gill nets at night, mainly in the river below Hartford. Some fishing occurs during the day when the water is especially turbid. Fyke, trap, or pound nets are now allowed in the river during the shad run. The primary market is for roe (eggs). Males (buck shad) have little value. Connecticut carefully regulates commercial fishing for shad on the Connecticut River. The season is open

Table 7. Annual commercial landings (x 1,000 lb) of American shad for different regions along the U.S. coast, 1960-1983. Code: NE = New England, MA = Mid-Atlantic, CB = Chesapeake Bay, SA = South Atlantic, PC = Pacific Coast (1960-1977 National Marine Fisheries Service, Statistical Digest; 1978-1983 National Marine Fisheries Service, unpublished data).

	Coastal region				
Year	NE	MA	CB	SA	PC
1960	432	1,237	2,682	1,614	456
1961	547	1,026	3,144	1,612	927
1962	470	841	3,795	2,167	1,586
1963	325	744	3,139	1,734	1,503
1964	320	721	3,541	1,687	818
1965	380	635	4,298	2,379	870
1966	279	379	3,564	1,736	1,347
1967	754	387	3,005	1,562	1,333
1968	218	379	3,508	2,052	862
1969	201	342	3,540	1,904	610
1970	186	314	5,151	1,851	724
1971	283	222	2,473	1,452	499
1972	264	375	3,014	1,091	709
1973	261	308	3,033	685	483
1974	257	294	1,789	655	511
1975	208	337	1,321	518	522
1976	412	322	1,006	320	481
1977	418	394	1,547	418	560
1978	361	245	1,322	976	545
1979	330	216	1,041	363	797
1980	253	406	998	839	277
1981	66	510	500	1,235	120
1982	403	757	590	1,033	429
1983	504	365	242	1,974	413

to commercial fishing from April 1 to June 15. During the season, fishing is prohibited from Friday sunset to Sunday sunset. Monofilament gill nets are prohibited and the gill nets used must have a minimum stretch of 5 inches (127 mm). There are no size or sex restrictions and a commercial fishing license is required. Catch information is reasonably accurate because license holders must complete a report of fishing at the end of each season, and Connecticut biologists have validated this method of reporting catch statistics (Eric Smith, Conn. Dep. Environ. Prot.; pers. comm.).

Sportfishing for shad in Connecticut is permitted from April 1 to a published closing date determined each year. In streams, angling and scoop nets are permitted; the bag limit is six fish per day.

Population Dynamics

The population dynamics of American shad in the Connecticut River

is similar to other fishes with high fecundity (Leggett 1976; Leggett 1977b; Marcy 1976). About 64% of the annual variation in the production of juvenile shad was directly related to the number of spawners in the spring run; 22% of the variation was attributed to water temperature and flow characteristics during the run (Marcy 1976).

The rate of exploitation was a major factor influencing the number of fish in the spawning run in the Connecticut River (Leggett 1976). The fishery removed significant numbers of adults just prior to spawning, and because the eggs are the most desirable fish product, fully mature females are the principal targets of the fishery.

The number of adults that survive the fishery are directly correlated with the number of fish produced in the next generation. This relationship is described by a stock-recruitment equation:

$$R = N e^{0.7\,(1 - N/87)}$$

where R is recruitment and N is the parent stock in terms of numbers of eggs (Leggett 1976).

Average instantaneous natural mortality of spawners was less after the Connecticut Yankee Atomic Power Plant began operation (Table 8).

Table 8. Average instantaneous natural mortality rates of adults (standard deviations in parentheses) before and during Connecticut Yankee Atomic Power Plant operation (Leggett 1976).

	Instantaneous mortality	
Sex	Pre-operation 1965-1967	Operation 1968-1973
Males	1.5(1.2)	0.7(0.6)
Females	1.2(0.7)	0.7(0.4)

The Delaware River shad population was made up mostly of Age IV males and Age VI females (Table 9). Males first appeared in the runs at Age III whereas females first appeared at Age IV. Few males Age VI and females Age VII were observed (Chittenden 1975).

ECOLOGICAL ROLE

The diet of juvenile American shad in freshwater is diverse; insects and crustaceans are most common (Walburg 1960). Early larvae feed mostly on cyclopoid copepods and tendipedids (Levesque and Reed 1972). Juveniles eat food in the water column, not on the bottom, and Domermuth and Reed (1980) reported that juvenile shad were selective of what they ate; the diet consisted of 20% bosminids and 51% daphnids.

After going to sea, the American shad feeds on a variety of small crustacea, many of which are associated with the bottom. Mysids dominate their diet in the Bay of Fundy (Leim 1924). Adults also feed on copepods, small fishes, euphausids, fish eggs, and amphipods (Bigelow and

Table 9. Age structure of the American shad population in the Delaware River (Chittenden 1975).

Sex	Age	Number	%
Males			
	II	1	0.0
	III	8	2.6
	IV	236	76.1
	V	62	20.0
	VI	3	0.0
Females			
	IV	50	13.7
	V	225	61.6
	VI	88	24.1
	VII	2	0.0

Schroeder 1963; Scott and Crossman 1973). Shad probably have a diel vertical migration to follow the diel migration of their principal food, zooplankton (Neves and Depres 1979).

Although investigators believe that few shad feed in freshwater, American shad placed in a freshwater pond fed on artificial feed (Atkinson 1951).

Predators take large numbers of American shad in both freshwater and the sea. Juvenile shad in rivers are eaten by juvenile bass (Morone saxatilis), American eels (Anguilla rostrata), and birds. At sea, adult shad fall prey to seals, sharks, bluefin tuna (Thunnus thynnus), kingfish (Scomberomorus regalis), and porpoises (Scott and Crossman 1973). None of these predators depend solely on shad for food; in fact, shad appear to be of minor importance as food in rivers or the ocean.

The American shad has the usual complement of parasites and diseases. Acanthocephala, parasitic copepods, distomes, nematodes, and trematodes have all been reported in or on shad. The sea lamprey (Petromyzon marinus) and freshwater lampreys (Ichthyomyzon sp.) have been observed attached to adult shad in the Connecticut River (Walburg and Nichols 1967).

ENVIRONMENTAL REQUIREMENTS

Salinity

The American shad is euryhaline and adapts readily to either freshwater or seawater during its anadromous migrations. The adults require 2 or 3 days to adapt to freshwater as evidenced by their wandering in estuaries before entering the rivers (Leggett 1976). The transfer of adult shad from seawater to freshwater over a 2.5-h period caused physiologic stress and high mortality (Leggett and O'Boyle 1976).

American shad eggs are always deposited in freshwater but whether they hatch only in freshwater, only in brackish water, or in both is not certain. An experiment reported by Leim (1924) showed that eggs and larvae can tolerate brackish water of 7.5 to 15 ppt, but not 22.5 ppt. He also reported that hatching success of eggs was higher in brackish and full strength seawater than in freshwater, but the findings were based only on nine eggs.

Temperature

Most shad spawn in rivers at water temperatures of 12 to 18 °C, or 54 to 64 °F (Leggett and Whitney 1972). Leim (1924) claimed that American shad eggs hatch in 12 to 15 days at 12 °C (54 °F) and 6 to 8 days at 17 °C (63 °F). He also noted that eggs cease developing at 7 °C (45 °F), and abnormalities develop at 22 °C (72 °F). Leim used the same experimental design described in the salinity section, except that freshwater was used for the temperature experiments.

The American shad avoids cold water when possible. The lower thermal tolerance limit is about 2 °C (36 °F); prolonged exposure to 4 to 6 °C (39 to 43 °F) is sublethal and too cold for full body functioning (Chittenden 1972). When given a choice, young shad avoid temperatures below 8 °C (46 °F) and stringently avoid temperatures below 5 °C (41 °F). Chittenden concluded that cold water released below reservoirs may adversely affect spawning and nursery areas downstream.

American shad also avoid rapid increases in temperature. Tests in tanks showed that shad avoided temperature increases of about 4 °C (7 °F) above the acclimation temperature (Moss 1970). Juveniles did not avoid changes of 1 °C (2 °F), suggesting a sensory threshold of between +1 and +4 °C (+2 and +7 °F)

above ambient temperature. Shad attempt to avoid potentially lethal temperatures. Field observations bear out these laboratory findings.

Migrations in the ocean and freshwater are closely tied to water temperature. Shad are most frequently caught commercially in ocean bottom temperatures of 7 to 13 °C (45 to 55 °F) (Neves and Depres 1979).

Oxygen

The American shad lives in well oxygenated environments in rivers and in the sea. Dissolved oxygen concentrations must be 4 to 5 mg/l (ppm) in headponds through which shad pass in their migration (Jessop 1975). Chittenden (1969) reports that at dissolved oxygen concentrations below 3 mg/l, equilibrium is lost, at concentrations below 2 mg/l, heavy mortality occurs, and at less than 0.6 mg/l, all fish die immediately. Shad eggs were absent where dissolved oxygen was lower than 5 mg/l (Marcy 1976). Carlson (1968) reports the oxygen LC_{50} for Connecticut River shad eggs is 2.0 to 2.5 mg/l.

Turbidity

Talbot (1954) concluded that extensive dredging of the Hudson River produced no measurable adverse effects on shad abundance. Adult shad readily enter the Shubenacadie River in Nova Scotia, where turbidity is 1 g/l (Leim 1924). As part of a laboratory assessment, Auld and Schubel (1978) reported that suspended sediment concentrations up to 1 g/l did not significantly affect hatching success; however, concentrations greater than 0.1 g/l for 96 h significantly reduced the survival of shad larvae. Larvae therefore are much less tolerant of suspended sediments than eggs.

Substrate

Substrate type apparently is unimportant to shad because fish spawn in the water column and the eggs are carried downstream. Shad have been observed to spawn over sand, silt, muck, gravel, and boulder substrate (Mansueti and Kolb 1953; Walburg 1960; Leggett 1976).

Depth

Depth is not a critical factor to the American shad. Fish in spawning runs are caught at all depths. For example, Mansueti and Kolb (1953), Walburg (1960), and Kuzmeskus (1977) reported fish spawning at depths from 0.45 to 7 m (1.5 to 23 ft).

Juveniles live at depths of 0.9 to 4.9 m (3 to 16 ft) in the Connecticut River (Marcy 1976). The abundance was related more to distance upstream rather than to depth. During the day, 87% of the juvenile shad caught in a gillnet were near the bottom at depths of 3.7 to 4.9 m (12 to 16 ft). At night all were caught near the surface.

At sea, shad are near the bottom during the day and disperse throughout the water column at night (Neves and Depres 1979).

Water Movement

Water velocity is critical because shad must negotiate river currents and fishways when migrating upstream and must go over spillways when swimming downstream. Adult shad migrating upstream are reluctant to use older, traditional fishways, because entrance widths, depths, and flows are often unsuitable (Walburg and Nichols 1967). Pool-and-weir and vertical-baffle fishways and elevators are much more efficient. For the pool-and-weir fishway, optimum difference in pool elevations is 23 cm (9 in) when water velocities are 61 to 91 cm/sec (2 to 3 ft/sec). For any fish passage to work, sufficient water volume and velocity at the entrance is essential. In the Connecticut River

the daily movement of shad upstream was 4.6 km (2.9 mi) in brackish water, and 14 km (9 mi) in freshwater (Leggett 1976).

Adult downstream migration depends on water currents and the pattern of currents around obstructions. The rate of flow into a fishway accounted for 60% of the variation in the number of downstream migrants in a fishway (Moffitt 1979). Without attractant flow, no fish entered the fishway. Fish that fail to find the downstream passage must pass over the spillway or through hydroelectric turbines.

Tests by Gloss (1982) showed that 57% to 80% of juvenile shad that passed through a 850 kw Ossberger turbine were killed outright; those that survived died later of stress and predation, or from the delayed effects of scale loss or injuries caused by the fishway itself. At Mactaquac, New Brunswick, Jessop (1975) found that at least 25% of the shad died as a result of physical stress caused by a fish-lift. Jessop (1975) also reported that exposure to lethal nitrogen supersaturation in waters below dams may cause mortality.

American shad spawn at water velocities of 10 to 132 cm/sec (<1 to 4 ft/sec), according to Kuzmeskus (1977). Spawning usually takes place at velocities of 30 to 90 cm/sec (1 to 3 ft/sec) (Walburg 1960).

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries on the taxonomy, morphology, distribution, life history, and environmental requirements of coastal aquatic species. They are designed to assist in environmental impact assessment. After a drastic decline in abundance, the American shad (Alosa sapidissima) is being restored in many of the rivers along the East Coast that originally supported large runs. The American shad is an anadromous fish that lives several years in the ocean and returns to its natal river to spawn in the spring when temperatures reach 12°C. The eggs are carried by currents downstream from spawning sites in large rivers for 8-12 days until they hatch. The larvae, which metamorphose to the juvenile stage in 3-4 weeks, remain in the river until fall when they migrate to the sea. Shad move offshore and southward during winter at water temperatures of 3-15°C. American shad feed on zooplankton. They adapt readily to fresh - or saltwater, but they prefer salinities exceeding 4 ppt.

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Estuaries	Salinity	Animal migrations
Fishes	Temperature	Suspended sediments
Growth	Fisheries	Rivers
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